Light WIMPs And Equivalent Neutrinos

Gary Steigman

The Ohio State University

(With K. M. Nollett, Ohio University)

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Very light WIMPs, thermal relics, annihilate late in the early Universe, changing the energy and entropy densities at BBN and at recombination. BBN, in combination with the CMB, can remove some of the degeneracies among light WIMPs and equivalent neutrinos, constraining the existence and properties of each.

(Steigman, Phys. Rev. D 87 (2013) 103517)

BBN & The CMB Confront A Light WIMP

In the presence of a light ($m_\chi \leq 20$ MeV)

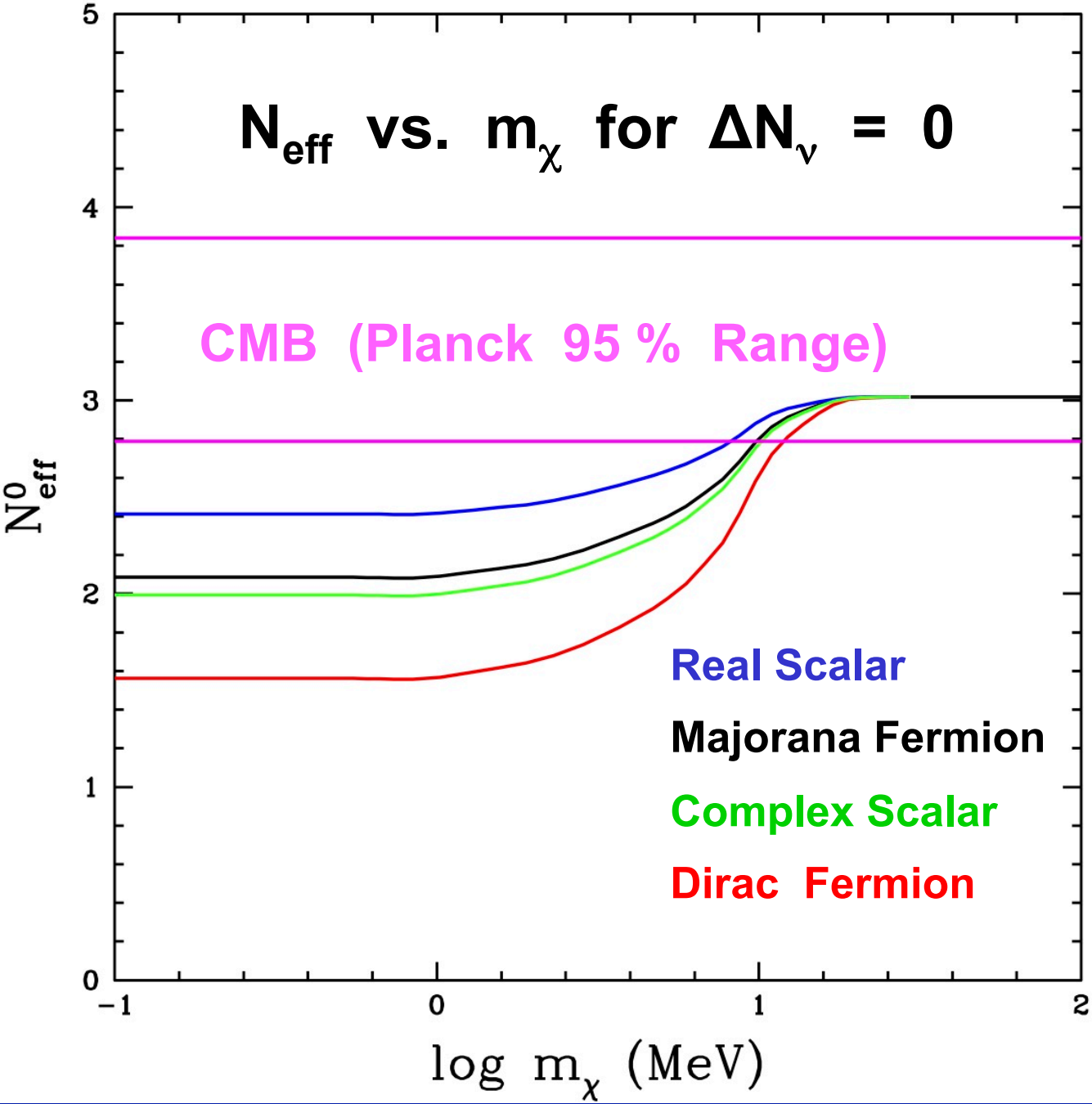
WIMP* the effective number of neutrinos

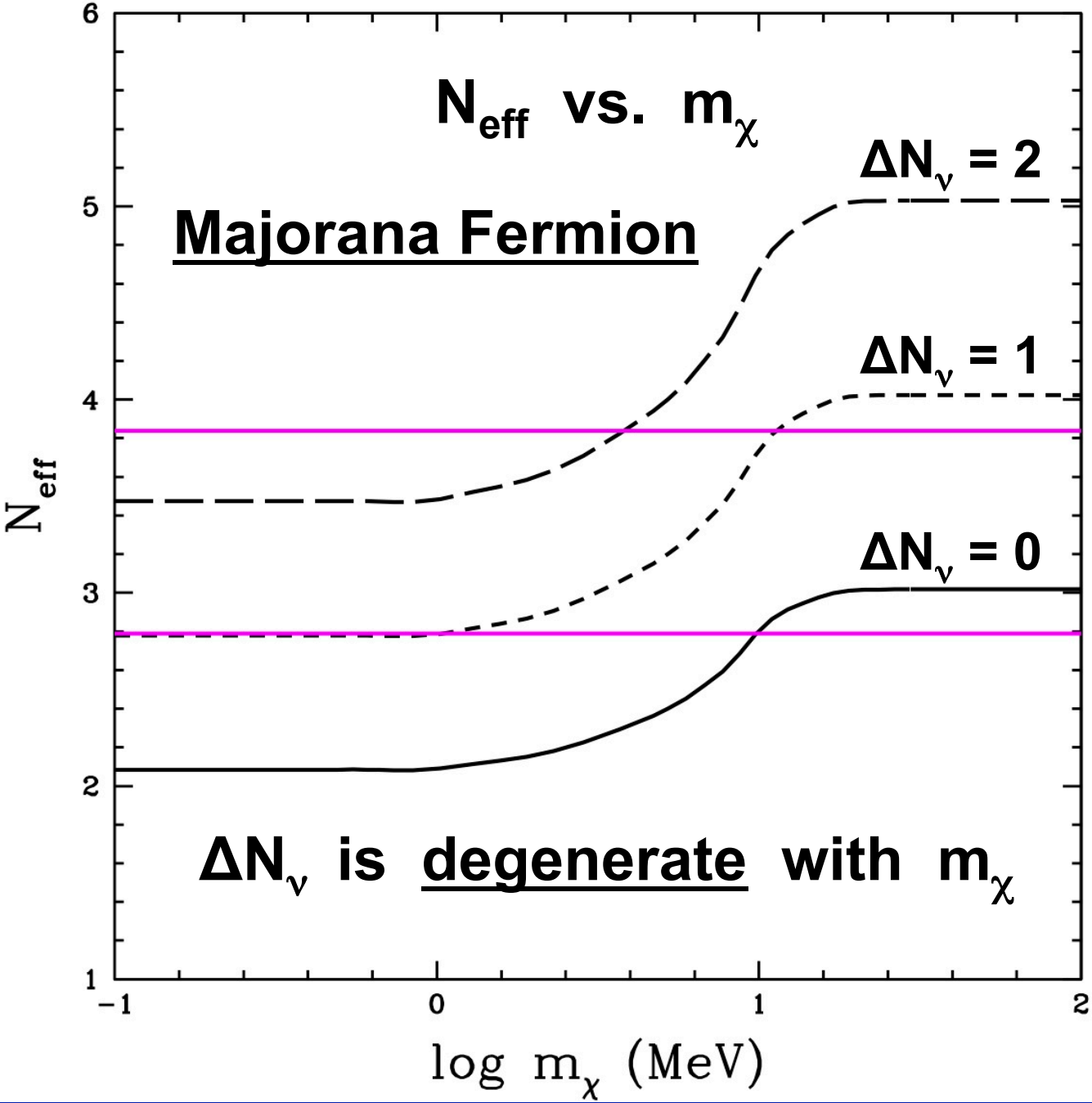
$$N_{eff} = N^0_{eff} (1 + \Delta N_\nu / 3)$$

where N^0_{eff} depends on the WIMP mass and

ΔN_ν is the number of equivalent neutrinos

* Electromagnetically Coupled


N_{eff} vs. m_χ for $\Delta N_\nu = 0$
CMB (Planck 95 % Range)
Real Scalar
Majorana Fermion
Complex Scalar
Dirac Fermion
N^0_{eff}
log m_χ (MeV)
5
4
3
2
1
0
−1
0
1
2


N_{eff} vs. m_χ
Majorana Fermion
$\Delta N_\nu = 2$
$\Delta N_\nu = 1$
$\Delta N_\nu = 0$
ΔN_ν is degenerate with m_χ
N_{eff}
log m_χ (MeV)
6
5
4
3
2
1
−1
0
1
2

BBN And The CMB WITHOUT A Light WIMP ($N^0_{eff} \approx 3.05$)

CMB (Planck 2013)

$N_{eff} = 3.30 \pm 0.27$; $\Omega_B h^2 = 0.0223 \pm 0.0003$

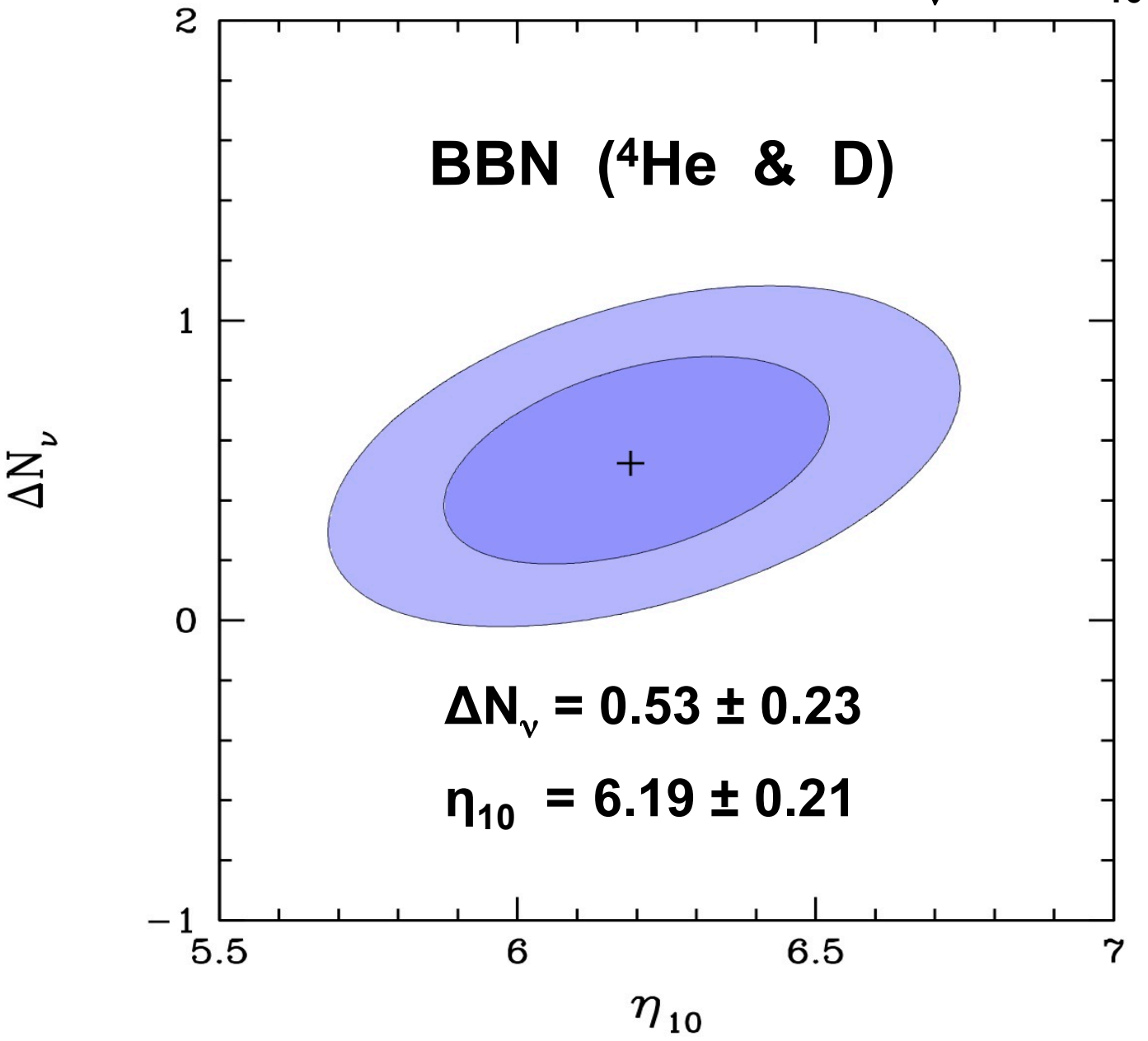
$(\eta_{10} = 10^{10} (n_B / n_\gamma)_0 = 273.9\, \Omega_B h^2 = 6.11 \pm 0.08)$

BBN (Primordial Abundances Of D And ^{4}He)

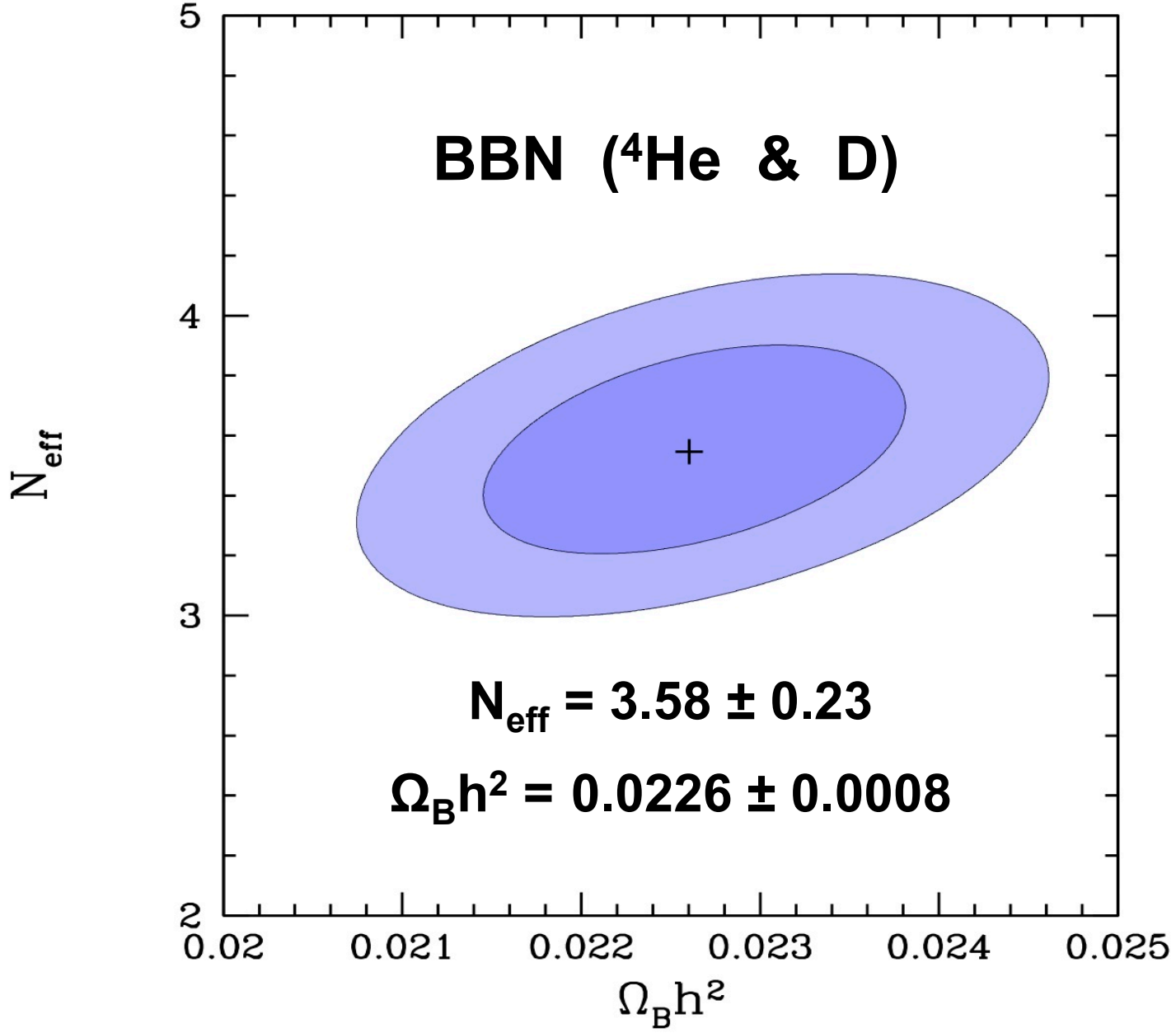
$Y_P = 0.254 \pm 0.003$ (Izotov et al. 2013)

$y_{DP} = 10^5 (D/H)_P = 2.60 \pm 0.12$ (Pettini & Cooke 2012)

68 % & 95 % Contours of ΔN_ν vs. η_{10}



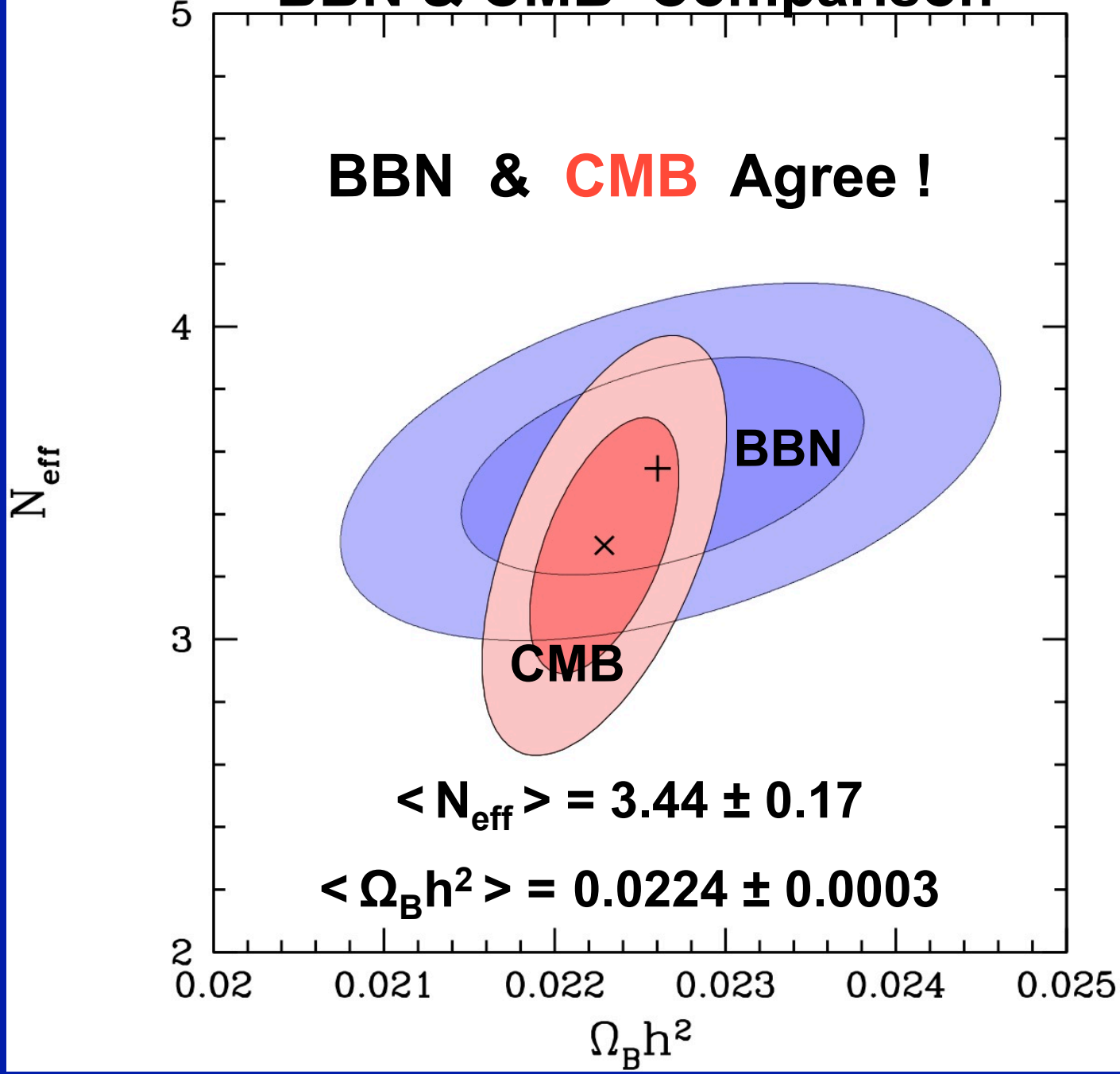
68 % & 95 % Contours of N_{eff} vs. $\Omega_B h^2$



$N_{eff} = 3.58 \pm 0.23$

$\Omega_B h^2 = 0.0226 \pm 0.0008$

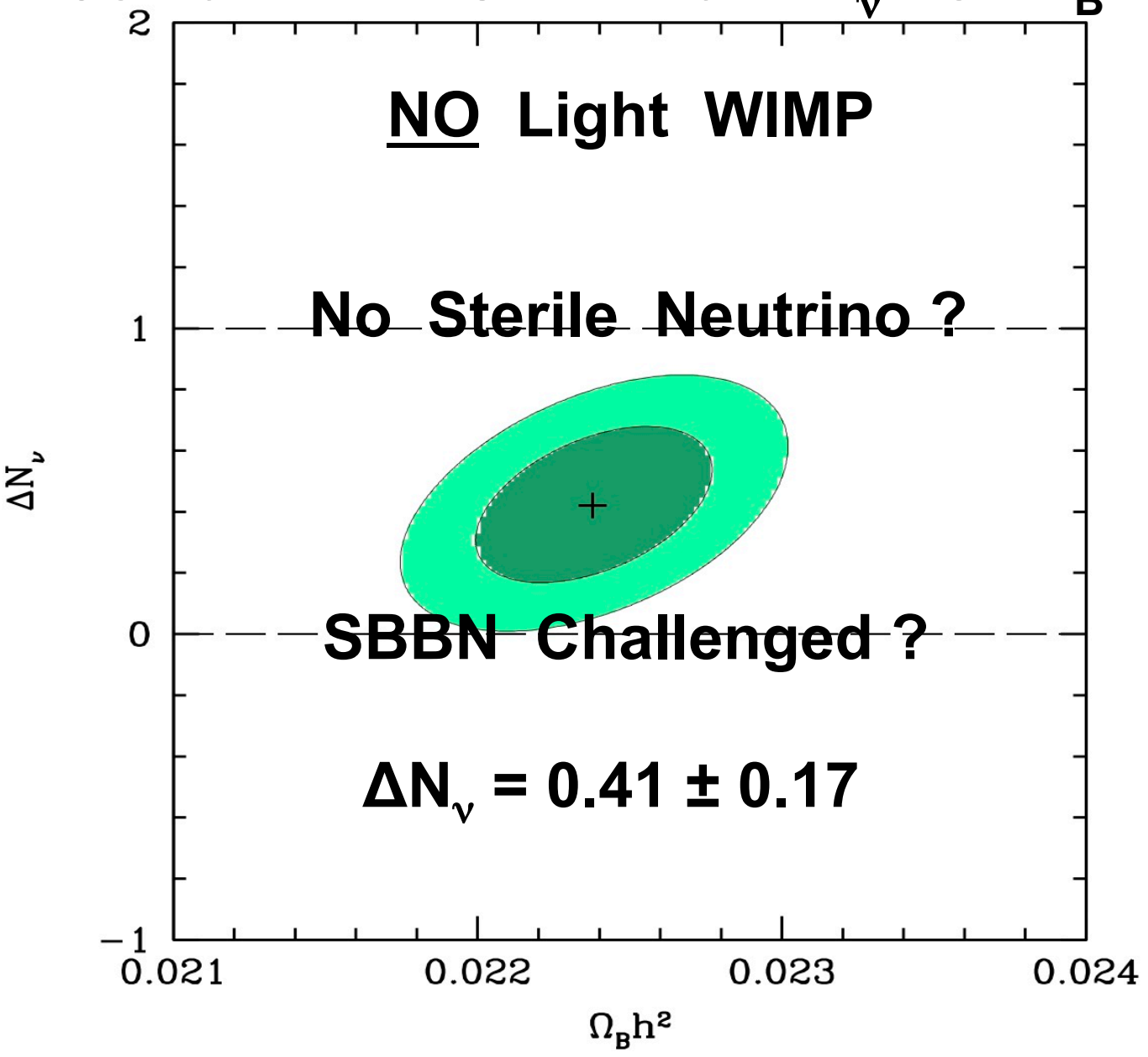
BBN & CMB Comparison



$< N_{eff} > = 3.44 \pm 0.17$

$< \Omega_B h^2 > = 0.0224 \pm 0.0003$

Joint BBN + CMB Fit: ΔN_ν vs. $\Omega_B h^2$



Joint BBN + CMB Fit (No Light WIMP)

$< N_{eff} > = 3.44 \pm 0.17$

$< \Omega_B h^2 > = 0.0224 \pm 0.0003 \quad (\eta_{10} = 6.13 \pm 0.07)$

But ! $\Delta N_\nu = 0.41 \pm 0.17$

$\Delta N_\nu = 0$ (SBBN) @ $\sim 2.4\,\sigma$

$\Delta N_\nu = 1$ (e. g., a sterile ν) @ $\sim 3.5\,\sigma$

Neither $\Delta N_\nu = 0$ nor $\Delta N_\nu = 1$ is favored

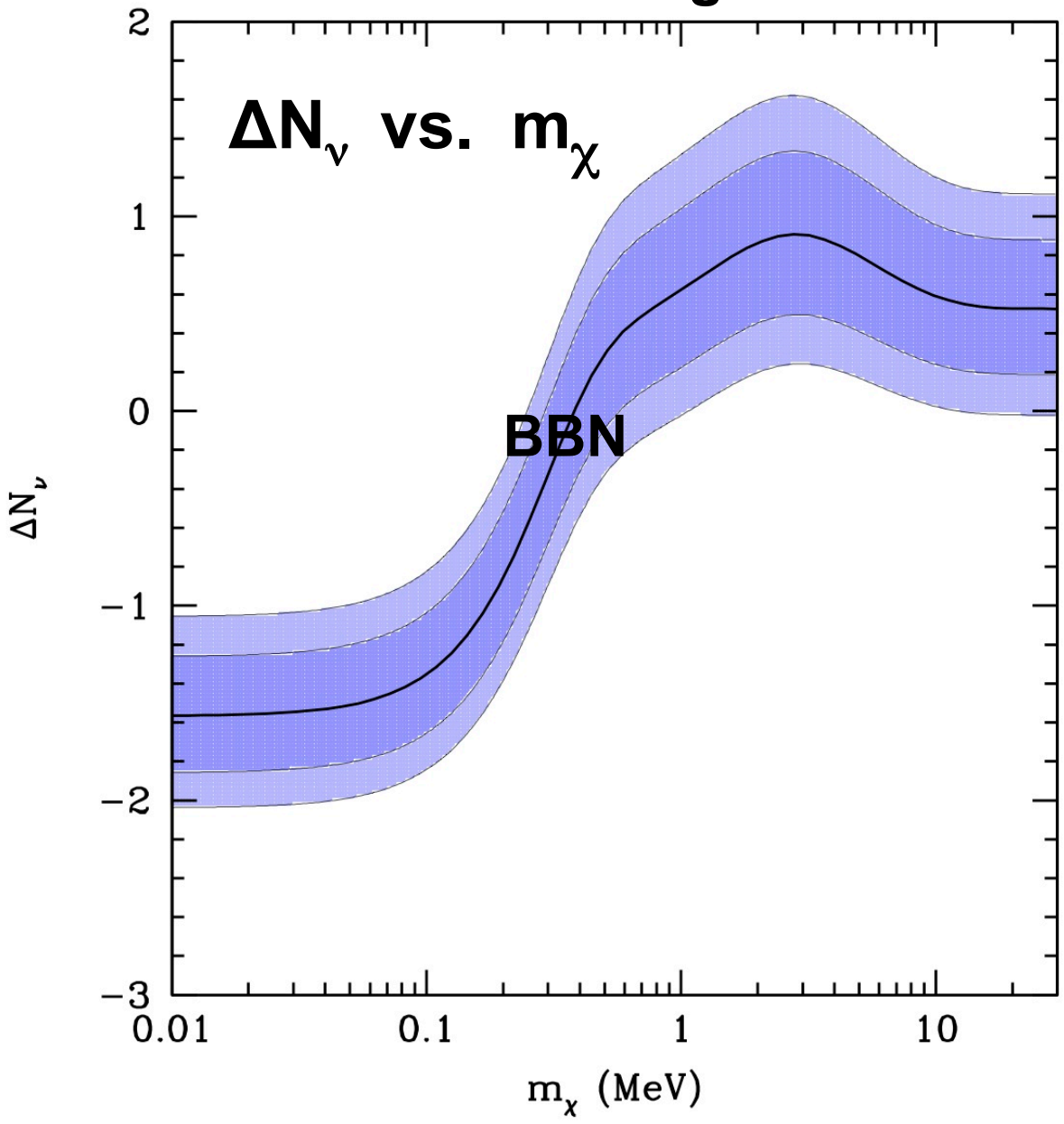
BBN And The CMB WITH A Light WIMP

For each value of m_χ, a pair of $\{\eta_{10}, \Delta N_\nu\}$ (or, $\{\Omega_B h^2, N_{eff}\}$) values can be found that yield the observed BBN abundances of ^{4}He and D

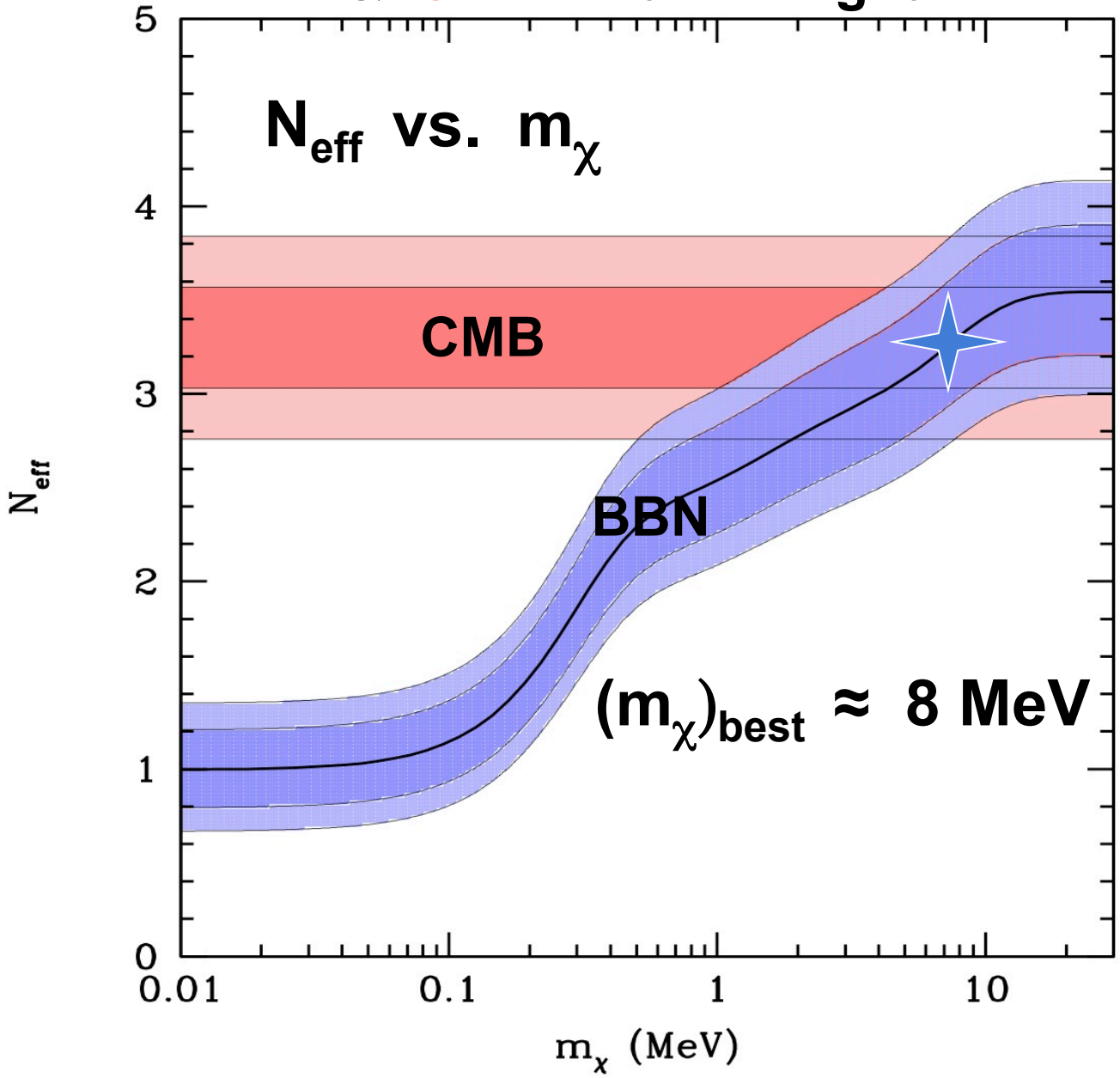
CMB independently constrains $\{\Omega_B h^2, N_{eff}\}$

How do BBN and the CMB compare ?

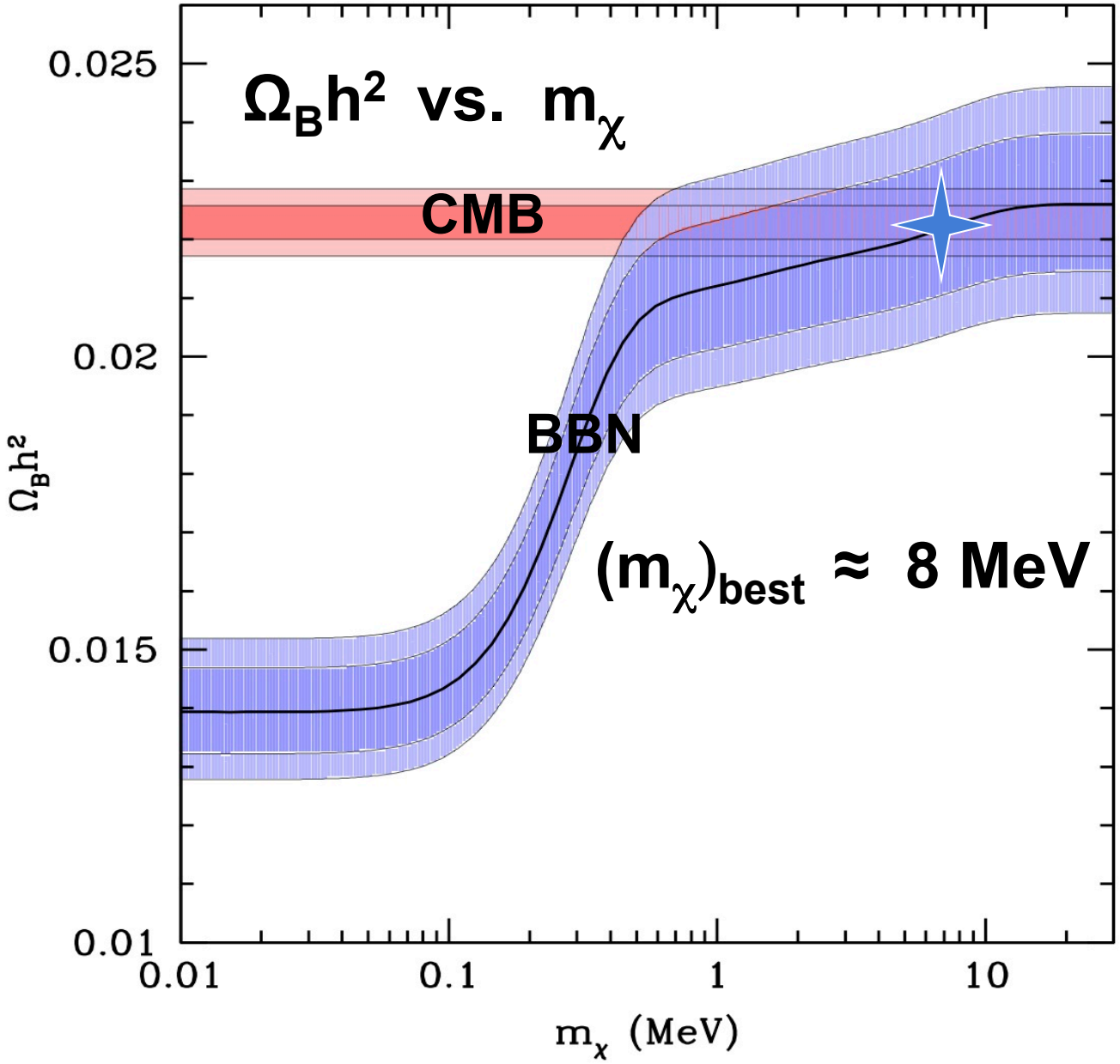
BBN With A Light WIMP



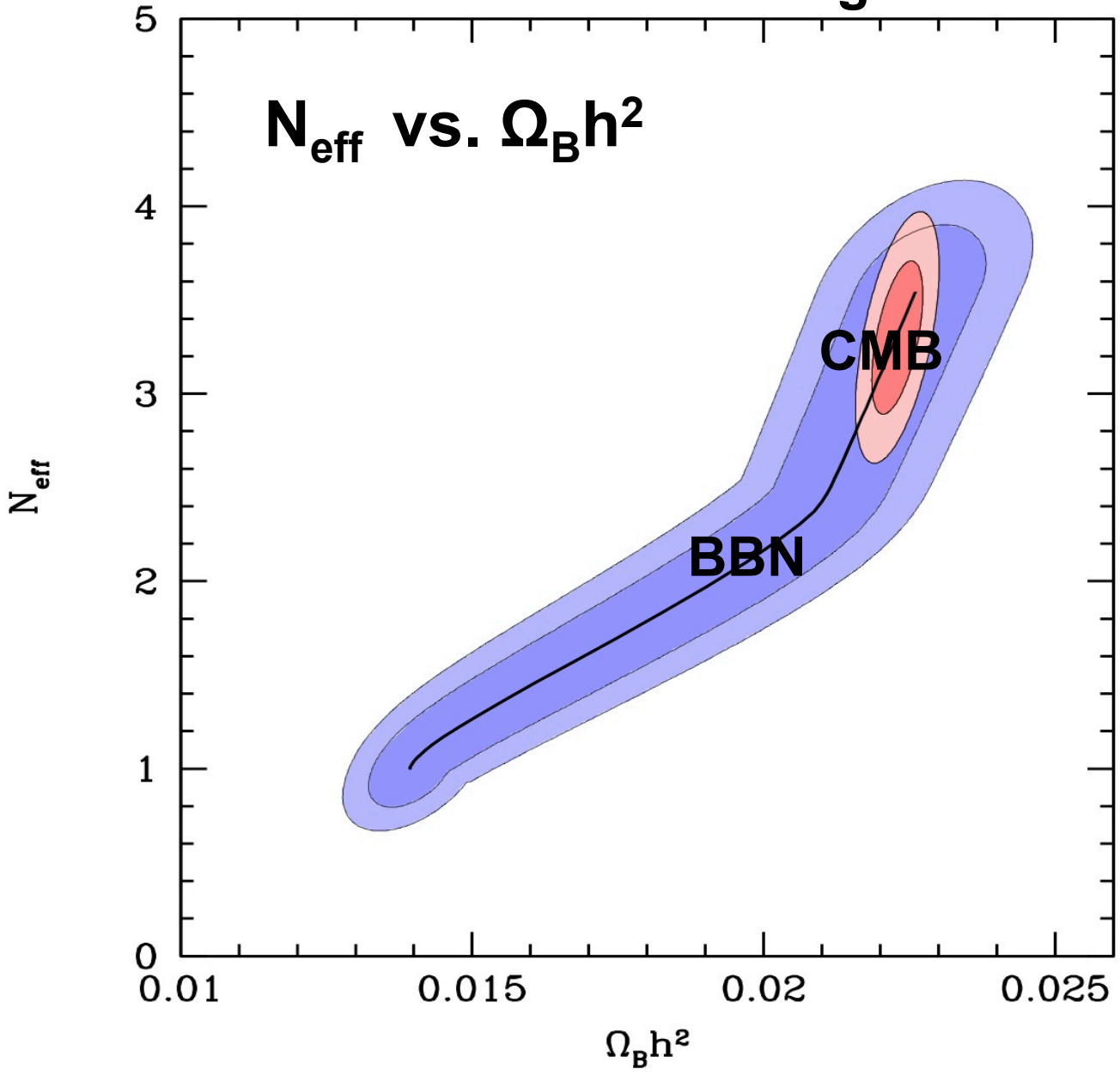
BBN & CMB With A Light WIMP



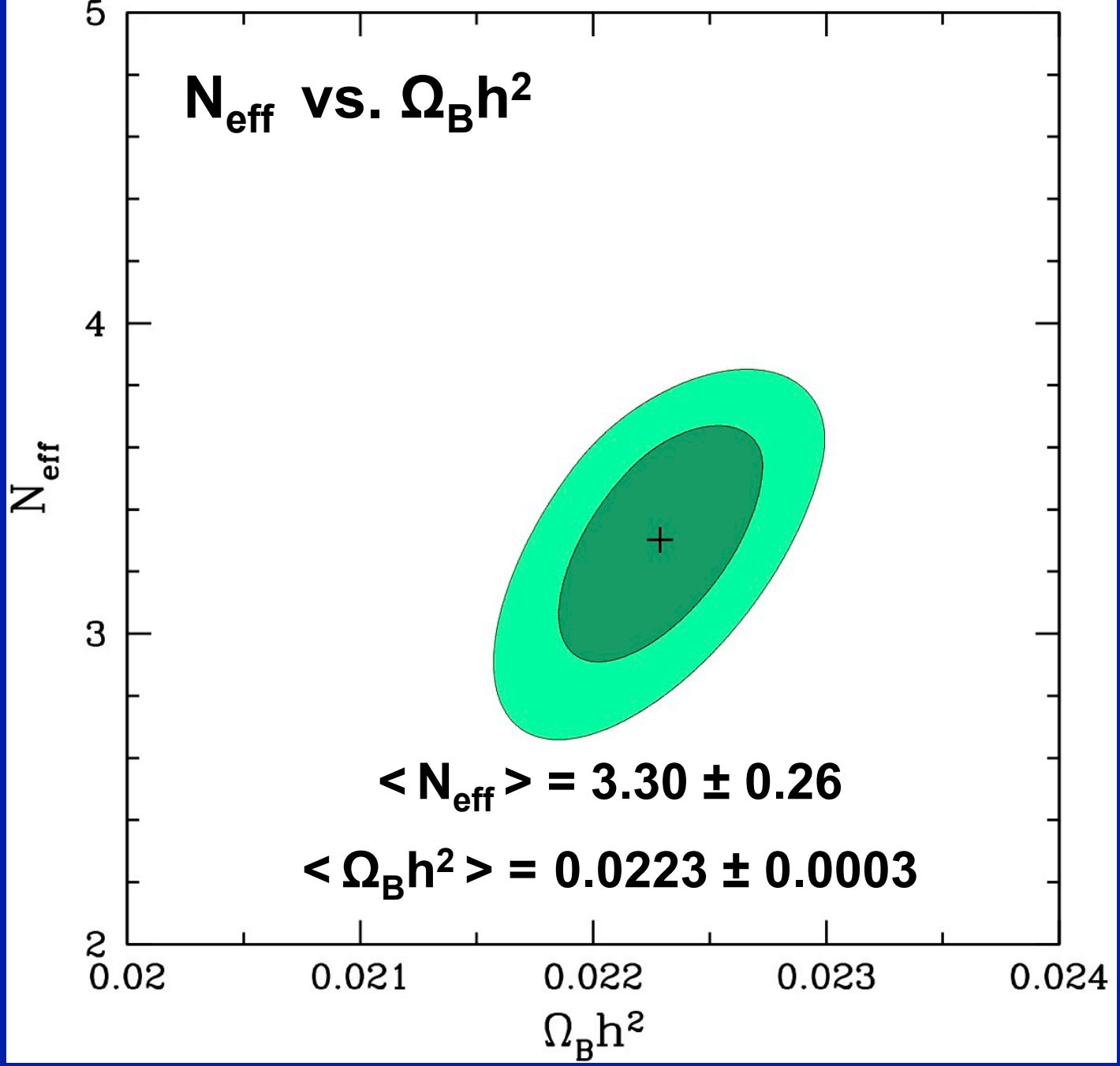
BBN & CMB With A Light WIMP



BBN & CMB With A Light WIMP

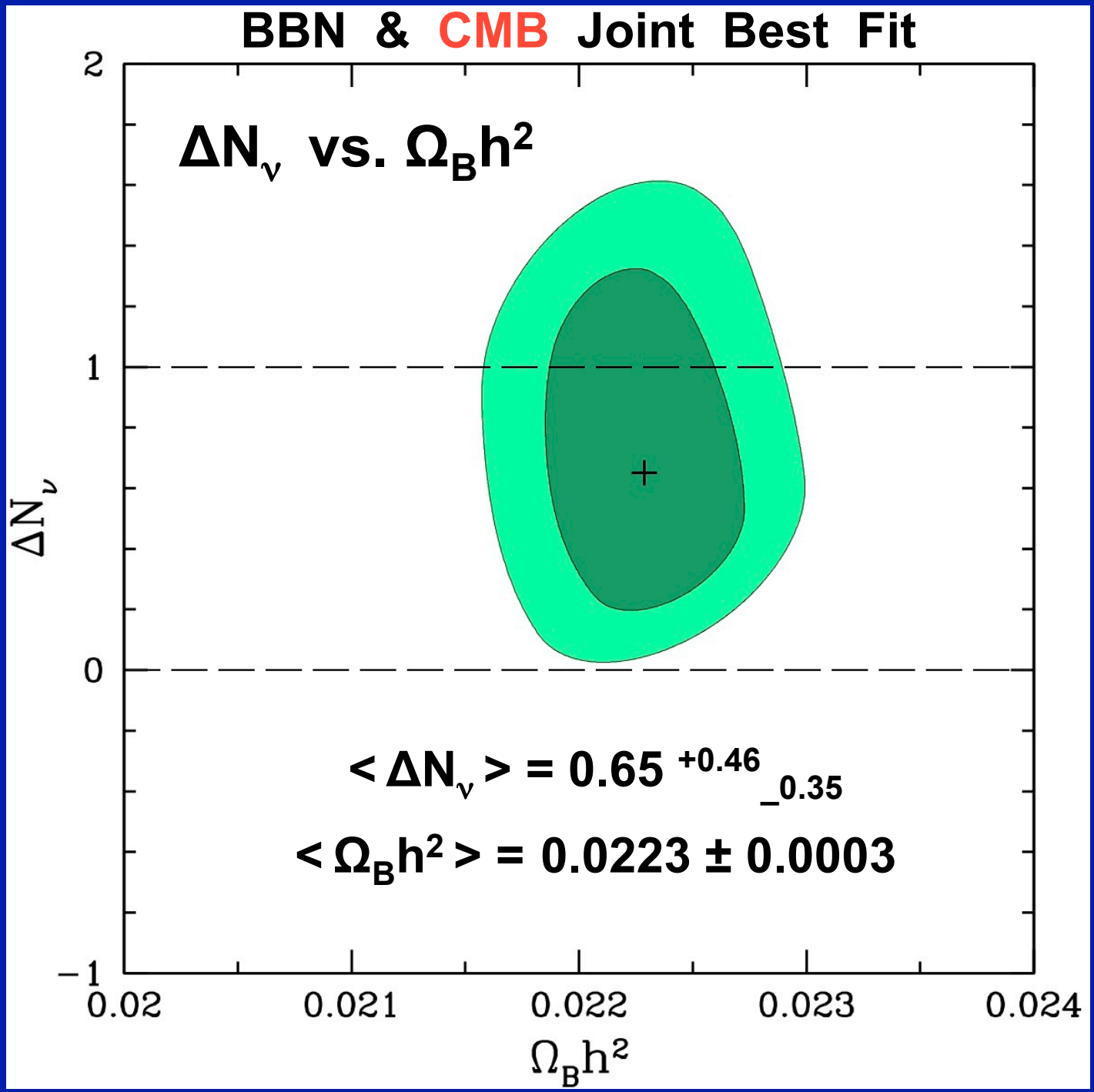


BBN & CMB Joint Best Fit



$< N_{eff} > = 3.30 \pm 0.26$

$< \Omega_B h^2 > = 0.0223 \pm 0.0003$


BBN & CMB Joint Best Fit
ΔN_ν vs. Ω_B h²
2
1
0
−1
ΔN_ν
0.02
0.021
0.022
0.023
0.024
Ω_B h²
< ΔN_ν > = 0.65 +0.46 _0.35
< Ω_B h² > = 0.0223 ± 0.0003

SUMMARY

In the absence of a Light WIMP, BBN and the CMB agree, but SBBN ($\Delta N_\nu = 0$) and a sterile neutrino ($\Delta N_\nu = 1$) are disfavored

In the presence of a Light WIMP, BBN and the CMB set a lower bound to $m_\chi > \sim 2$ MeV and, they favor $m_\chi \approx 8$ MeV and $\Delta N_\nu \approx 0.65$

$\bar{\nu}$

α β χ ϖ δ ε φ γ η ι φ κ λ μ ν ο π θ ρ σ τ υ ω ξ ψ ζ

Δ Φ Γ ϑ Λ Μ Π Θ Ρ Σ Ω Ξ Ψ